

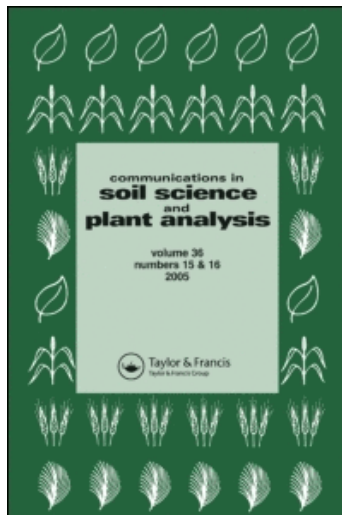
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Utilizing Existing Sensor Technology to Predict Spring Wheat Grain Nitrogen Concentration

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Optimum grain nitrogen (N) concentration and yield in spring wheat (Triticum aestivum L.) can be problematic without proper N fertilizer management. Sensor-based technologies have been used for application of fertilizers and also to predict yield in wheat, although little has been done in the prediction of grain N. Field studies were conducted in South Dakota in 2006 (Gettysburg, Bath, and Cresbard) and 2007 (Gettysburg, Aurora, Leola, and Artas). There were five N treatments (0, 56, 112, 168, and 224 kg N ha⁻¹) applied pre-plant with a second N application applied foliar at anthesis. Sensor readings were taken at growth stages Feekes 10, anthesis, and postfoliar application using the GreenSeeker Hand Held optical sensor. Grain samples were taken at maturity and analyzed for total N. Using similar information collected in 2003 and 2005, a critical normalized difference vegetation index (NDVI) value was determined using the Cate–Nelson procedure. The critical NDVI value needed to ensure optimum grain N was 0.70. In 2006 and 2007, the plots that received an application of N at anthesis had higher grain N than the plots not receiving N. There was also a significant response between applied N and grain yield. The results show that with further studies, the Greenseeker could be used to apply N to maximize yield and grain N in a precise and accurate manner.

Keywords Nitrogen, precision agriculture, remote sensing

Introduction

Remote sensing, in particular using ground-based sensors, has been used extensively in the past to predict in-season nitrogen (N) status and yield in winter wheat in the southern plains of the United States. It has also shown promise in predicting grain yield in spring wheat in South Dakota. Can we use a ground-based sensor to predict grain N concentration in spring wheat in South Dakota? The ability to predict grain N concentration in season will be beneficial to producers because it can eliminate overapplication of N in season and ensure the optimum grain N concentration to receive the grain N concentration premium. Reducing overapplication of N will lead to a reduction in N leaching into the groundwater (Hong et al. 2006).

Because of their geographic location, producers in the northern Great Plains can take advantage of the possible grain N concentration premium because harvest has already

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occurred in the southern Great Plains. This will determine whether it will be economical to use this type of technology based upon the grain N concentration premium, the cost of N fertilizer, and grain price at the time of application. If the protein premium is low, it may not be economical to apply N at anthesis to increase grain N concentration. If the protein premium is high, it could be economical to apply N at anthesis to ensure the proper grain N concentration to receive the premium (Baker et al. 2004). The research objective was to utilize a commercially available remote-sensing instrument (Greenseeker) to develop a critical normalized difference vegetation index (NDVI) value as a tool when applying foliar N. This critical value will be utilized to ensure adequate grain N concentration to receive the protein premium in spring wheat grain.

The Greenseeker (Ntech Industries, Ukiah, Calif.) has been used extensively by researchers in Oklahoma, where the sensor was developed. Researchers there have utilized the sensor for determining yield in bermudagrass (*Cynodon dactylon* L.), which has proven to be successful because NDVI was highly correlated with forage yield (Mosali et al. 2007). Research has also been conducted on corn at various growth stages in Oklahoma and Nebraska for determining grain yield. The results have proven to be successful when plant height is considered along with NDVI, thus refining recommendations for in-season N application (Freeman et al. 2007). Research conducted on winter wheat using the Greenseeker has also been promising, with NDVI being highly correlated with grain yield, grain N uptake, and total plant N uptake, although grain N concentration could not be predicted with NDVI in this particular study (Freeman et al. 2003).

Research conducted in South Dakota to determine if ground-based sensors (Greenseeker) can be used to predict yield in spring wheat, as it has been used in the southern Great Plains, has been promising (Osborne 2007). The results presented in our study further solidify the use of ground-based sensors in South Dakota for N management in spring wheat. Additional research on the Greenseeker is currently being conducted at several state universities including the University of Nebraska, South Dakota State University, North Dakota State University, Iowa State University, Virginia Tech, and Kansas State University on corn, spring wheat, winter wheat, canola, and barley. The research objective was to utilize a commercially available remote-sensing instrument (Greenseeker) to develop a critical NDVI value as a tool when applying foliar N to ensure adequate grain N concentration to receive the protein premium in spring wheat grain. This was done by using previously collected data and testing and validating this critical value with additional information collected in multiple years and locations.

Materials and Methods

Experiments were conducted at four locations in eastern and central South Dakota during the 2006 and 2007 growing seasons. Plots were located near Bath, Cresbard, and Gettysburg, South Dakota, in 2006 and near Artas, Aurora, Gettysburg, and Leola, South Dakota, in 2007. During the previous growing season (2005), all fields were no-till and planted to sunflowers. The spring wheat variety Briggs was planted at all sites at a seeding rate of 486,000 kernels ha^{-1} in 2006. The spring wheat variety Traverse was planted at all sites at a seeding rate of 486,000 kernel plants ha^{-1} in 2007. The planting dates and plot sizes for the locations in 2006 and 2007 are listed in Table 1. Initial soil-test characteristics and soil classification by experimental location are reported in Tables 2 and 3, respectively.

The experimental design was split-plot design with four replications. Whole-plot treatments included five N rates (0, 56, 112, 168, and 224 kg N ha^{-1}) applied at planting as

Table 1
Agronomic information for all locations, 2006 and 2007

Location	Planting	Feekes 6 ^a	Feekes 10 ^a	Anthesis	Foliar	Postfoliar application	Harvest application
2006							
Artas	5 April	25 May	7 June	—	—	—	—
Bath	12 April	30 May	8 June	21 June	22 June	27 June	17 July
Cresbard	11 April	30 May	8 June	21 June	22 June	27 June	17 July
Gettysburg	5 April	25 May	7 June	—	22 June	—	17 July
2007							
Artas	17 April	31 May	19 June	—	28 June	27 June	25 July
Aurora	19 April	24 May	12 June	18 June	29 June	26 June	24 July
Cresbard	17 April	31 May	19 June	—	27 June	27 June	25 July
Gettysburg	18 April	31 May	14 June	19 June	27 June	27 June	25 July

^aBiomass samples were taken at these growth stages.

Table 2
Initial soil-test characteristics at all locations, 2006 and 2007

Location	OM ^a (%)	NO ³ -N ^b (kg ha ⁻¹)	SO ⁴ -S ^b (kg ha ⁻¹)	Cl ^b (kg ha ⁻¹)	P ^a (ppm)	K ^a (ppm)	pH ^a
2006							
Artas	2.6	14.6	11.2	15.7	4	353	7.2
Bath	3.2	19.0	53.8	24.6	3	341	7.1
Cresbard	3.2	22.4	80.6	11.2	8	701	5.7
Gettysburg	2.4	17.9	17.9	26.9	8	329	7.1
2007							
Artas	2.8	67.2	40.3	29.1	13	452	6.8
Aurora	3.8	17.9	91.8	24.6	10	250	5.9
Gettysburg	2.8	127.7	44.8	24.6	10	350	7.4
Leola	4.3	80.6	51.5	56.0	20	473	6.5

^aAnalysis on 0–15.2 cm.

^bAnalysis on 0–61 cm.

ammonium nitrate. Split-plot treatment was a foliar N application applied at anthesis as urea ammonium nitrate (28%) at a rate of 33 kg N ha⁻¹ (Table 1). Phosphorus (P) and potassium (K) were applied so they would not to be limiting during the growing season.

In 2006 and 2007, normalized difference vegetation index (NDVI) sensor readings were taken at Feekes 5 or 6 and 10 (Table 1) at all locations with Greenseeker model 505 handheld optical sensor (Ntech Industries, Ukiah, Calif.). The readings were collected at a height of 1 m above the canopy for two separate areas measuring 0.3 × 0.6 m in each field. One of the sample sites was removed at the time of sampling to get an estimate of biomass production, and the other area was marked for future grain yield harvest. The grain yield area was designated at Feekes 5 or 6 sampling time and marked as such, and all sensor readings were collected from this area. Additional sensor readings were collected on the

Table 3
Soil types and taxonomic classes at all locations, 2006 and 2007

Location	Soil type	Taxonomic class
Artas	Williams–Bowbells	Williams: fine-loamy, mixed, superactive, frigid Typic Argiustolls Bowbells: fine-loamy, mixed, superactive, frigid Pachic Argiustolls
Aurora	Brandt silty clay loam	Fine-silty, mixed, superactive, frigid Calcic Hapludolls
Bath	Great Bend silt loam	Fine-silty, mixed, superactive, frigid Calcic Hapludolls
Cresbard	Williams–Bowbells loams	Williams: fine-loamy, mixed, superactive, frigid Typic Argiustolls Bowbells: fine-loamy, mixed, superactive frigid Pachic Argiustolls
Gettysburg 2006	Agar silt loam	Fine-silty, mixed, superactive, mesic Typic Argiustolls
Gettysburg 2007	Agar–Mobridge loam	Agar: fine-silty, mixed, superactive, mesic Typic Argiustolls Mobridge: fine-silty, mixed, superactive, mesic Pachic Argiustolls
Leola	Williams–Bowbells–Tonka complex	Williams: fine-loamy, mixed, superactive, frigid Typic Argiustolls Bowbells: fine-loamy, mixed, superactive, frigid Pachic Argiustolls Tonka: fine, smectitic, frigid Argiaquic Argialbolls

designated yield area at anthesis and postfoliar application depending on weather and crop growth at various locations (Table 1).

Biomass samples were taken at the Feekes 10 growth stages to determine dry-matter production and N concentration. Biomass samples were collected on the exact areas in which sensor readings were collected. The samples were dried in a forced-air oven at 60 °C for 120 h. Dry samples were weighed to determine total biomass production, then finely ground to pass a 2-mm sieve. Plant N concentration was determined using a Leco dry combustion unit (Leco Corporation, St. Joseph, Mich.). Nitrogen uptake was determined by multiplying the total N concentration by the dry plant biomass.

Designated yield spots in all plots were hand harvested. Wheat heads were hand threshed, dried, and weighed to determine yield. Grain yield was calculated and corrected to 130 g kg⁻¹ moisture. The grain was finely ground to pass a 2-mm sieve, and N concentration was determined using a Leco dry combustion unit. Statistical analyses were performed on plant biomass, grain yield, grain N concentration, and N uptake using the GLM procedure in SAS (SAS Institute 1999). At all locations each year, there was not significant N rate by foliar N application interaction; therefore, only main effects are discussed throughout the manuscript.

Table 4
Calculations used in the Cate–Nelson procedure, 2003 and 2005

NDVI	Mean 1	CSS ^a 1	Mean 2	CSS ^a 2	R ²
0.56	13.8	3.7	14.9	435.2	0.90
0.62	14.0	11.7	14.9	425.9	0.91
0.68	13.9	15.0	15.0	419.2	0.92
0.70^b	14.0	22.9	15.1	409.4	0.93
0.73	13.9	25.2	15.2	405.7	0.92
0.74	13.9	29.9	15.2	391.2	0.88
0.76	13.8	34.6	15.3	370.8	0.81
0.78	13.9	19.7	15.5	354.9	0.81

^aCorrected sums of square.
^bCritical NDVI value for predicting grain N concentration in spring wheat in South Dakota.

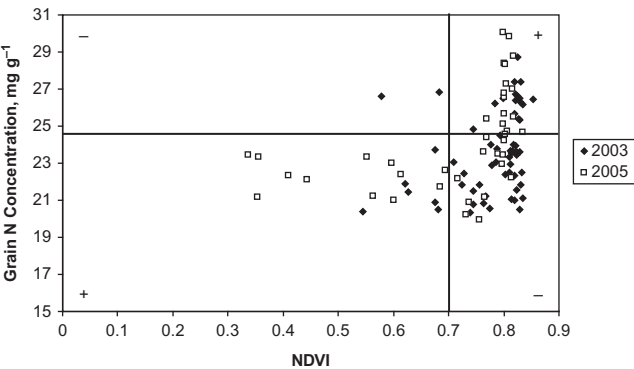


Figure 1. Cate–Nelson graphical illustration of the NDVI critical value (0.70) developed from previously collected data at the Feekes 10 growth stage (Osborne 2007).

The critical NDVI reading was calculated by utilizing previous data collected by Osborne (2007). The critical NDVI value is the NDVI reading that ensures the optimum grain N concentration to receive the grain N concentration premium. The Cate–Nelson procedure was utilized to develop the critical value (Cate and Nelson 1971). Previous sensor readings collected at Feekes 10 growth stage were utilized within the analysis and compared to grain N concentration (Table 4; Figure 1). The Cate–Nelson graph is separated into four different areas, two areas with a positive outcome (upper right and lower left, as indicated with a + sign) and two areas with a negative outcome (lower right and upper left, as indicated with a – sign).

Results and Discussion

Environmental Conditions

The growing conditions in season played a significant role in the outcome of these experiments. In 2006, rainfall was much less than normal throughout the growing season (April–July) (Figure 2), with all locations receiving between 30% and 80% of normal

Table 5
Average treatment biomass yield for samples collected at the Feekes 10 growth stage, 2006 and 2007

Treatment foliar app. (Y/N) ^a	N rate, (kg ha ⁻¹)	Biomass (kg ha ⁻¹)					
		Artas	Bath	Cresbard	Gettysburg	Aurora	Leola
2006							
N	0	621	424	617	416		
Y	0	635	553	652	438		
N	56	884	2167	1375	1090		
Y	56	810	1958	1475	1345		
N	112	935	2424	1797	1219		
Y	112	972	2130	1836	1335		
N	168	1001	2589	1920	1361		
Y	168	873	2554	1689	1683		
N	224	912	2168	1502	1605		
Y	224	834	2273	1868	1282		
2007							
N	0	1421			1801	1486	1504
Y	0	1424			1834	1188	1045
N	56	3092			3804	2424	2900
Y	56	3137			3433	1953	2916
N	112	3659			3284	2988	3090
Y	112	4648			3846	2742	3089
N	168	2718			3828	2847	2969
Y	168	4696			4076	2582	2682
N	224	4362			5726	2756	3085
Y	224	4135			3893	2988	3409

^aN: No foliar application of N at anthesis. Y: Foliar (5.5 kg N ha⁻¹) application of N at anthesis.

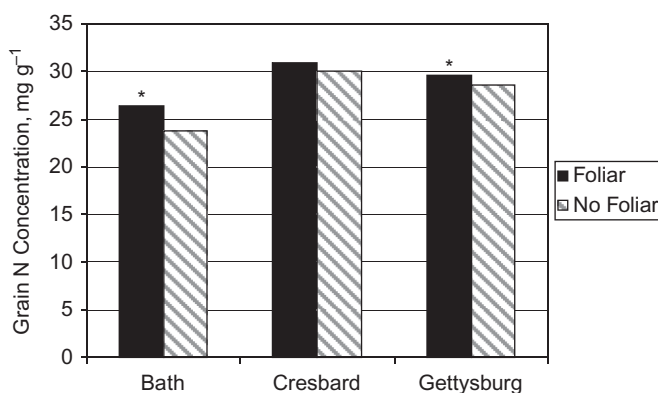


Figure 2. Average grain N concentration with and without foliar N application at each location, 2006. (*Significant at the 0.05 probability level.)

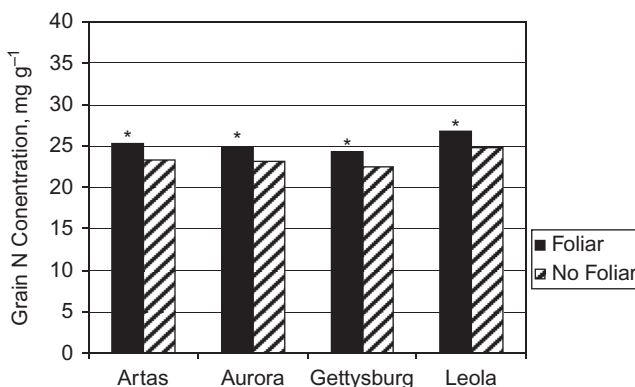


Figure 3. Average grain N concentration with and without foliar N application at each location. (*Significant at the 0.05 probability level.)

precipitation for that period of time (Figure 3). Because of the reduction in precipitation in 2006, grain N concentration was high. This can be caused by a surplus of N applied at planting that was not utilized for vegetative growth because of the lack of moisture (Terman et al. 1969; Fowler et al. 1990). A foliar application was not necessary because grain N concentration values were more than adequate to receive a premium without additional N. Although foliar applications did significantly increase grain N concentration at most locations, the lack of moisture not only affected the yield and grain N concentration but also affected the plant vegetative growth. Because of the lack of adequate moisture, plant height was an average of 30 cm while headed. This is a defense mechanism for the plant; it shortens its life cycle to produce as much grain as possible as the stress increases (Barnabás, Jäger, and Feher 2008). Average temperatures throughout the growing season were slightly above normal but were probably not high enough to cause detriment to crop yields.

In 2007, rainfall was closer to normal at sites than for 2006, except at Aurora, where rainfall was less than normal for the growing season (Figure 3). It was slightly dry at all locations during the early part of the growing season (April) but timely rainfalls in May and June increased plant growth and development (Figure 2). Temperatures were normal throughout the growing season and had no adverse effect on the crop. Grain N concentrations were typical of a normal growing environment. Because of the normal growing environment, the plants were able to utilize soil N for normal growth and therefore N-deficient plots needed a foliar application of N to increase grain N to receive the premium.

Results in 2006

The spring wheat variety Briggs was planted in 2006. Briggs was released in 2002 by the South Dakota Agricultural Experiment Station; it is a tall, semidwarf, hard red spring wheat that matures early and has average grain N concentration and better than average test weight. The plots at Bath and Gettysburg, which received N at anthesis, had significantly higher grain N concentrations than the plots that did not receive foliar N. At Cresbard, the foliar N application did not have a significant impact on grain N concentration. This can be attributed to the lack of moisture because grain N concentrations were already high

without the foliar application of N (Figure 2). Because of the reduction in precipitation in 2006, grain N concentration was high and growth at Feekes 10 biomass was low (Table 5). This can be caused by a surplus of N applied at planting that was not utilized for vegetative growth as a result of the lack of moisture (Terman et al. 1969; Fowler et al. 1990). The grain N concentration was such that a foliar application was not necessary as grain N concentration values were more than adequate to receive a premium without additional N. Although foliar applications did significantly increase grain N concentration at most locations, the lack of moisture not only affected the yield and grain N concentration but also affected the plant vegetative growth. Because of the lack of adequate moisture, plant height was an average of 30 cm while headed.

At all locations, N rates applied at planting significantly increased the grain N concentration and grain yield (Table 6). There was a significant increase in yield (2.5 times) for plots receiving N compared to those receiving no N at the Bath location, with maximum yield obtained at the 112 kg N ha⁻¹ N rate. Similarly, there was a yield response at the Gettysburg locations because of the application of N, although the difference between the N and no-N treatments was less. There was no significant difference in grain yield at the Cresbard locations during the 2006 growing season. Overall, grain yields at the Bath locations were greater than those at the other locations as a result of increased precipitation in 2006. Even with the drought conditions, there was a significant effect of N application on grain N concentration at locations with N concentrations increasing with increasing amounts of N. Maximum grain N concentration was obtained at 224 kg N ha⁻¹ for Bath, Gettysburg, and Cresbard.

Table 6
Average grain yield and grain N concentration means by N rate applied and foliar N application for all locations, 2006

N rate (kg ha ⁻¹)	Bath	Cresbard	Gettysburg
Grain yield (kg ha ⁻¹)			
0	1439 c ^a	1161 a	946 c
56	3649 b	1605 a	1609 a
112	4700 a	1449 a	1748 a
168	4615 a	1618 a	1338 b
224	4643 a	1663 a	1318 b
Foliar			
Yes	3835 a	1603 a	1424 a
No	3774 a	1396 a	1324 a
N concentration (mg g ⁻¹)			
0	23.10 c	24.00 c	21.50 d
56	20.80 d	30.10 b	27.10 c
112	24.60 b	32.30 a	29.90 b
168	28.00 a	32.70 a	33.20 a
224	29.10 a	33.20 a	33.60 a
Foliar			
Yes	26.44 a	30.98 a	29.68 a
No	23.82 b	30.02 a	28.54 b

^aThe values followed by the different letters within a column are significantly different at $p \leq 0.05$.

Table 7
Correlation coefficients for NDVI and grain N concentration, 2006

NDVI	Bath	Cresbard	Gettysburg	All Locations
Feekes 10	0.450**	0.731**	0.754**	0.191*
Anthesis	0.453**	0.432**	—	−0.176
Postfoliar	—	—	—	—

* Significant at the 0.05 probability level.

**Significant at the 0.001 probability level.

Simple correlation coefficients for grain N concentration with NDVI readings collected at Feekes 10, anthesis, and postanthesis N application by locations and year are shown in Table 7. Sensor readings collected at Feekes 10 and anthesis were significantly correlated with grain N concentration at all locations. There were not any sensor readings taken following postfoliar N application because of the drought conditions.

Results of 2007

Spring wheat variety Traverse was planted in 2007. Traverse was released in 2006 by the South Dakota Agricultural Experiment Station. The most important feature of Traverse is its high yield potential.

During the 2007 growing season, rainfall was not an issue; precipitation was slightly less than normal for Aurora and Leola, slightly more than normal for Gettysburg, and significantly more than normal at Artas. Foliar application of N at anthesis significantly increased grain N concentration at all locations (Figure 3).

The different N rates applied at planting significantly increased grain yield and grain N concentration at all locations, except for grain yield at the Leola location (Table 8). In contrast to the 2006 results, there were no dramatic differences between grain yields and grain N concentrations among the locations for the 2007 growing season. This was likely due to the near-normal precipitation received at most locations in 2007. There were no significant differences between grain yield and grain N concentration among the locations. Grain yields in 2007 were also significantly greater than in 2006 at all locations. Results from the Artas location showed that there was a 65% increase in grain yield between the plots that did not receive N at planting and the plots that received 56 kg N ha^{−1} at planting, with no significant difference in the other N rates. Similarly at Aurora, there was a 62% increase in grain yield between the plots that did not receive any N at planting and the plots that received 56 kg N ha^{−1}, with no difference between the N rate treatments. At Gettysburg, grain yield increased with increasing N applied, whereas at Leola there were no differences in grain yield as a result of applied N. Average grain yield at the Leola location was greater than at the other locations. The lack of a response to applied N at Leola could be attributed to a relatively high difference in residual soil nitrate levels (80 kg ha^{−1}) relative to maturity yields. Although the Gettysburg site had greater residual nitrate than did Leola (120 kg ha^{−1}) and also had greater yields, soil organic mineralization could have been much greater at the Leola site. Grain N concentration increased with increasing N applied up to the 168 kg N ha^{−1} N rate for Aurora, Gettysburg, and Leola, whereas at Artas, maximum grain N was obtained at the 112 kg N ha^{−1} N rate (Table 8). There was a

Table 8
Average grain yield and grain N concentration means by N rate applied and foliar N application for all locations, 2007

N rate (kg ha ⁻¹)	Artas	Aurora	Gettysburg	Leola
Grain yield (kg ha ⁻¹)				
0	2388 b ^a	2678 b	2650 c	3906 a
56	3938 a	4343 a	4502 b	4003 a
112	4181 a	4399 a	5260 ba	3793 a
168	4096 a	4133 a	5379 a	4114 a
224	4313 a	3817 a	5100 ba	4136 a
Foliar				
Yes	3896 a	3739 a	4538 a	3862 a
No	3669 b	4041 a	4604 a	4044 a
N concentration (mg g ⁻¹)				
0	22.30 b	19.80 d	21.10 c	23.10 c
56	22.20 b	22.50 c	20.30 d	23.20 c
112	24.90 a	25.00 b	24.10 b	26.60 b
168	25.60 a	26.10 a	25.60 a	27.70 a
224	26.60 a	26.40 a	26.20 a	28.10 a
Foliar				
Yes	25.26 a	24.88 a	24.34 a	26.72 a
No	23.34 b	23.06 b	22.58 b	24.78 b

^aThe values followed by different letters within a column are significantly different at $p \leq 0.05$.

significant positive effect of the foliar N application during the 2007 growing season with an increase in grain N at all locations (Figure 3).

Simple correlation coefficients estimated for the 2007 growing season for NDVI readings and grain N concentration found that there was a significant relationship at all sampling dates, except for the postfoliar sensor readings for Leola (Table 9). The lack of response at the Leola site was attributed to the lack of a N response, with no difference in grain yield or N concentration regardless of the N rate applied. This fair to good relationship indicates that the sensor could be used to predict grain N concentration in season.

Table 9
Correlation coefficients between NDVI and grain N concentration, 2007

NDVI	Artas	Aurora	Gettysburg	Leola	All locations
Feekes 10	0.565**	0.788**	0.513**	0.591**	0.543**
Anthesis	—	0.734**	—	0.555**	0.687**
Postfoliar	0.361*	0.629**	0.542**	0.21	0.426**

* Significant at the 0.05 probability level.

**Significant at the 0.001 probability level.

Cate–Nelson Procedure

The Cate–Nelson procedure is a simple method to determine critical levels or class limits and is commonly used in calibrating soil tests. The Cate–Nelson procedure indicates that 0.7 is the critical NDVI value to ensure the grain N concentration (grain protein) for spring wheat is 24.6 mg g^{-1} (14% protein) in the northern Great Plains (Table 4; Figure 1). A sensor reading greater than this critical value would signal that a foliar application of N at anthesis would not be necessary because grain N concentration would already be at or more than 24.6 mg g^{-1} (14% protein), whereas an NDVI reading less than this critical value would indicate that a foliar N application would be necessary to reach the critical point of 24.6 mg g^{-1} (14% protein) at grain harvest. Data collected in 2006 and 2007 were used to test this critical value, which was developed previously (Osborne 2007).

In the Cate–Nelson graph, there are four quadrants (two positive, two negative). Values located in the upper right (positive) quadrant are within range: the NDVI values would be more than the critical level, and grain N concentrations are more than the critical level. Thus, a foliar application of N would not be triggered. Values located in the lower right (negative) quadrant are not within the range: the NDVI values would be greater than the critical level, grain N concentrations would be less than the critical level, and foliar application of N would not be triggered when it is actually needed. Values located in the upper left (negative) quadrant are not within the acceptable range: the NDVI values would be less than the critical level, and grain N concentrations would be more than the critical level. A foliar N application would be triggered when it is not necessary because of the high grain N concentrations levels. Values located in the lower left (positive) quadrant are in the acceptable range: the NDVI values and the grain N concentration values would be less than the critical level and a foliar N application would be triggered when it was necessary.

In 2006, when the Feekes 10 NDVI was plotted against grain N concentration (Figure 4), 61% of the values were not within the accepted range (upper left and lower right). These sensor readings would have triggered an application of N to increase grain N concentration, but because of the environmental conditions of the growing season, grain N concentrations were already greater than the level needed for the premium. This decrease in

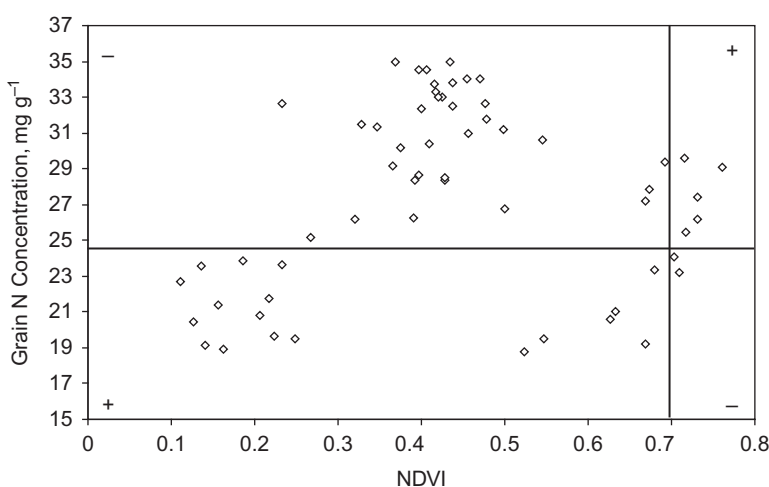


Figure 4. Feekes 10 NDVI readings and grain N concentration plotted with the Cate–Nelson procedure results superimposed, 2006.

precipitation caused high grain N concentration even when NDVI values were low. There was no anthesis sensor reading collected for the 2006 growing season. In practice, a producer would not consider applying late-season N because of the stress conditions, so in 2006 use of this type of technology would not have been needed.

In 2007, when the Feekes 10 NDVI was plotted against grain N concentration, 36% were not within the range and 64% were within the range (Figure 5). When the grain N concentration was plotted against the anthesis NDVI, 69% of the values were within the range and 31% were not within the range (Figure 6). These results indicate that sensor readings collected at the later growth stage more accurately predicted grain N concentration.

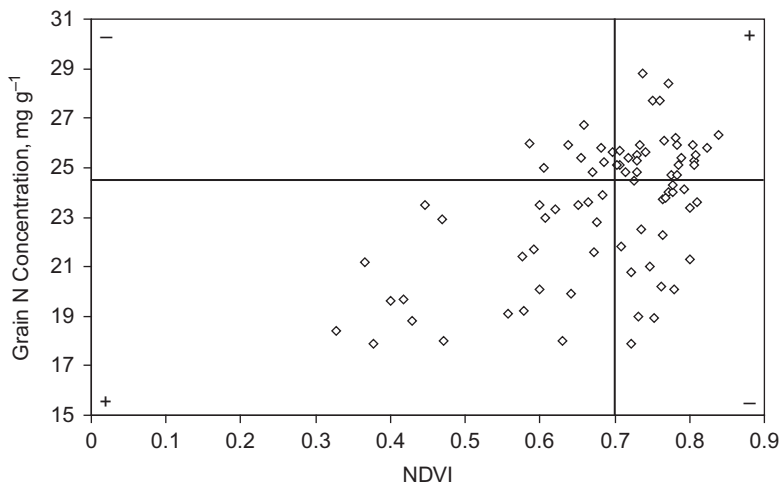


Figure 5. Feekes 10 NDVI readings and grain N concentration plotted with the Cate–Nelson procedure results superimposed, 2007.

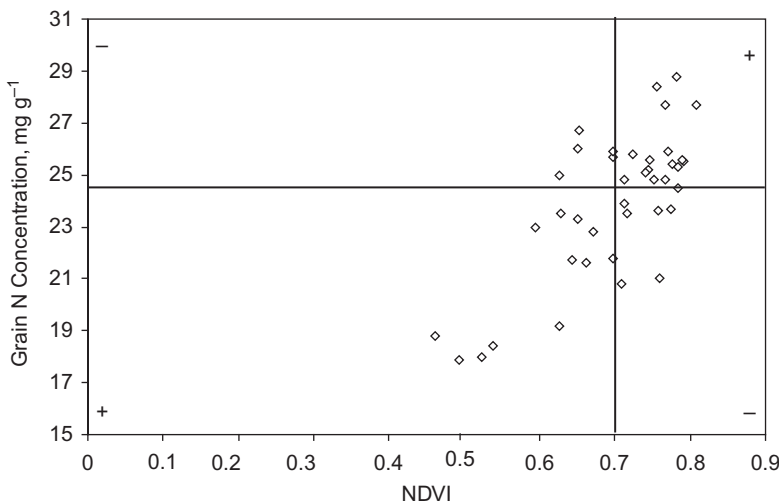


Figure 6. Anthesis NDVI readings and grain N concentration plotted with the Cate–Nelson procedure results superimposed, 2007.

Conclusions

The objective of this study was to determine if utilizing remote-sensing technology (Greenseeker) could predict grain N concentration in spring wheat. The rationale behind the experiment was that producers are paid a premium for grain that has an N concentration greater than 24.6 mg g⁻¹ (14% protein) and remote sensing might be utilized to determine if a late-season (postanthesis) N application was necessary to increase grain N and ensure that the grain N concentration premium is reached. The study was conducted during 2006 and 2007 at several locations each year. In 2006, precipitation was much less than normal, resulting in poor yields and high grain N concentrations. When the data were applied to the Cate–Nelson procedure, the majority of the values were out of range. An average producer or crop consultant would not be interested in utilizing this type of technology when environmental conditions were not adequate for proper production. The results from this research project further illustrate that under extreme environmental stress (drought), this technology does not give reliable results because of the stunted vegetative growth and yield. In 2007, environmental conditions were such that grain yields and N concentrations were normal. When the Feekes 10 data were applied to the Cate–Nelson procedure, 64% of the time the sensor responded appropriately. When the anthesis data were applied to the Cate–Nelson procedure, 69% of the time the sensor responded appropriately, indicating that the anthesis readings would be slightly better indicators of grain N concentration than Feekes 10 readings, although differences between the time periods was not great.

The next step in this research would be to refine the critical NDVI value with the newly collected data. Studies similar to this would need to continue over several years and locations to provide a more robust critical NDVI value. The research shows promise and has the potential to be beneficial to producers.

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